

CONGRESSIONAL BRIEFING

# METAMORPHIC MANUFACTURING

A New Frontier for Digital Manufacturing

Hosted by the House Manufacturing Caucus

Sponsored by The Minerals, Metals & Materials Society (TMS) and the United Engineering Foundation

June 6, 2019 • 12:00 pm – 1:30 pm  
2044 Rayburn House Office Building

TMS



IEEE★USA

AIChE  
The Global Home of Chemical Engineers

# What gave the U.S. its prosperity and influence?

# World-leading and enduring industries!

A few examples:

- Steel
  - Automobiles
  - Aerospace
  - Nuclear
  - Telecommunications
  - Petrochemical
  - Pharmaceuticals
  - Internet
- 
- Semiconductors
  - Machine tools
  - Solar Cells
  - Lithium-ion batteries

Artificial Intelligence?

# Detroit



Process innovation: Assembly line  
1924 Model T, Dearborn, MI

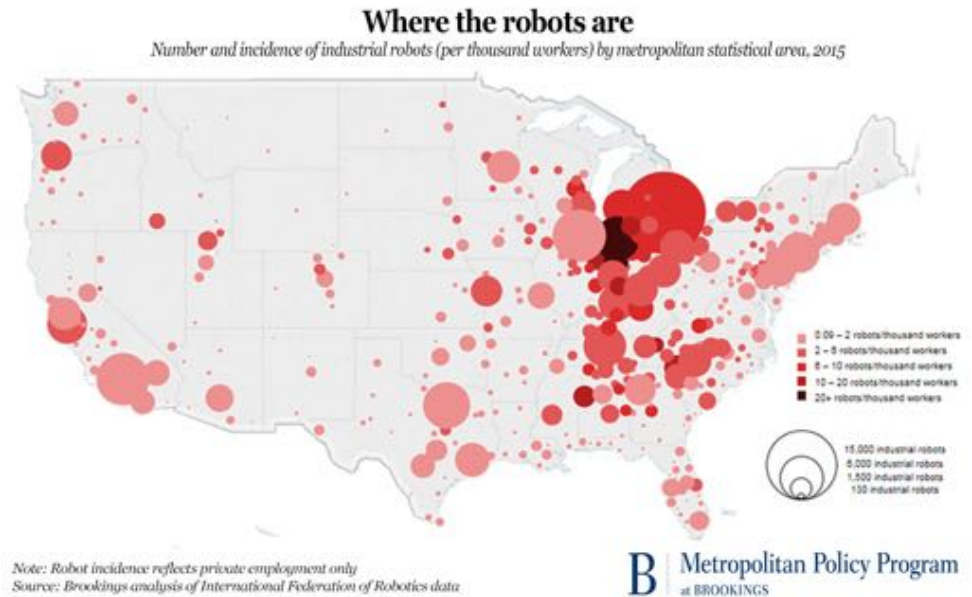


1920's – 1950's Detroit  
Wealthiest city in the world

# Detroit today – urban decay and world class skills



Detroit from above...



Heart of automation: N-S along I-75,  
E-W along I-90 Buffalo to Chicago

Hundreds of interconnected suppliers!!

## Ohio example – Honda assembly (Accord, Acura, etc.)



**About 600 North American Suppliers**

**Over \$20B/yr spend in N. America**

**Over \$10B/yr in Ohio alone**

**Lasting legacy of Henry Ford...**

# Old-School Process Innovation (Chinese Porcelain)



**Black Pottery Cauldron** Hemudu Culture Neolithic Period (ca. 5000 - 3000 B.C.). These cooking cauldrons from built-up layers of clay flakes, which were decorated with an overlapping rope pattern. They were placed over open fires.



Collection of Palace Museum, Beijing. Painted pottery pot with dragon and phoenix relief, as well as taotie designs for the lug handles. Western Han Dynasty, 206-8 B.C.

**Han dynasty developed Porcelain!! ~1200° C firing >500 years before Europe!**



Ming Dynasty: *Goldfish Vase*, reign of the [Jiajing Emperor \(1521-67\)](#); [Porcelain; Paris, Musée Guimet 261101](#)



Porcelain wares, such as those similar to these Yongle-era porcelain flasks, were often presented as trade goods during the 15th-century [Chinese maritime expeditions](#). [\(British Museum\)](#)



Han Dynasty Kiln

# Types of “Innovation”

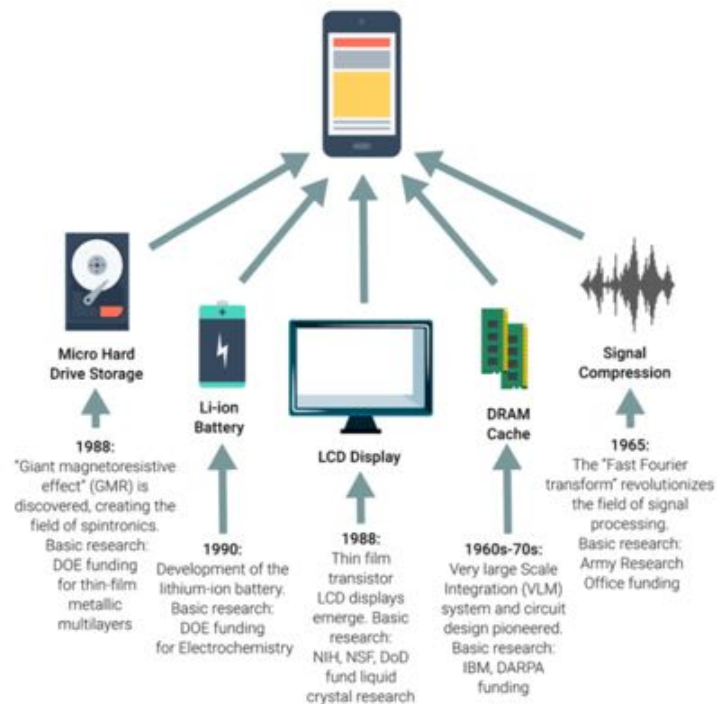
- Scientific Discovery (ideas)
  - US leads the world!
  - Provides Nobel Prizes and *ideas*.
- Product Innovation
  - Examples: iPhone, Dyson vacuum, IKEA furnishings, Tesla S
  - Can be fast
- Practice Innovation
  - Practices that involve new thinking or algorithms
  - Examples: Uber, Lean, AmazonPrime, Crowdsourcing, FedEx.
  - Can be fast
- (Physical) **Process Innovation**
  - Maturation of enabling physical processes; new hardware is involved.
  - Examples making: steel, aluminum, tires, glass, semiconductors, or new ways of mining, such as fracking.
  - Frustratingly slow... But provides sustained advantages



We need science,  
and to put it into production.

# Process and Product Innovation in the iPhone

## Ideas



## Factories & Jobs



**Major Asian companies get iPhone 6 job orders**

<b>LG Display</b>	<b>LG Display (South Korea)</b> The largest display panel supplier for iPhone 6
<b>Japan Display Inc.</b>	<b>Japan Display (Japan) and Innolux (Taiwan)</b> Also has major orders for iPhone 6 screens
<b>SONY</b>	<b>Sony (Japan)</b> Supplies both front and rear cameras
<b>TDK</b>	<b>TDK (Japan)</b> Major Apple supplier for inductor coils
<b>TOSHIBA</b>	<b>Toshiba (Japan) and SK Hynix (South Korea)</b> To supply storage at 16GB, 64GB, and 128GB
<b>tsmc</b>	<b>TSMC (Taiwan)</b> To supply Touch ID sensor for iPhone 6; the fingerprint technology debuted in iPhone 5S
<b>CATCHER</b>	<b>Catcher Technology (Taiwan) needs to catch up</b> The chassis supplier is fixing glitches in its casing, which may take 2-3 months; meanwhile, Apple switched to Jabil and Foxconn to meet the launching date.

Great discussion on this: Mforesight *Manufacturing Prosperity*,  
at <http://mforesight.org/download-reports/>

M Foresight summit: June 18 @ Hamilton Hotel, Sens. Rubio & Peters Keynote!

Infographics from: <http://comparecamp.com/how-where-iphone-is-made-comparison-of-apples-manufacturing-process/>

Another great event...



**Restoring the U.S. Innovation Ecosystem**  
2019 MFORESIGHT NATIONAL SUMMIT

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## FEATURED SPEAKERS

Senator Marco Rubio

Senator Gary Peters

Representative Ro Khanna

Representative Haley Stevens

David Anderson

President – SEMI Americas

Alan Shaffer

Deputy Undersecretary – Department of Defense

# Process innovation is precious and makes clusters

- New processes build persistent cluster economies
  - Detroit → Automotive
  - Akron → Elastomers / polymers
  - Wichita, KS → Airframe components
  - Seattle, WA → Airframes
  - Detroit → Automotive
  - Rochester, NY → Optics
  - Minneapolis → Medical Implants
  - Warsaw, IN → Orthopedic implants
  - Fort Wayne, IN → Electromagnets and wires
  - Corning, NY → Ceramics
  - Toledo, OH → Glass
  - **Shenzhen, China → Electronic systems**
- New processes teach new skills, and a culture of doing
- “Innovate here, build there” does not work!

## Incentives (become different in each country)

- **Government** – Employment, infrastructure, development.
- **Universities** – Happy & successful students, faculty and donors.
- **Companies** – Lucrative markets, low cost production, sources of innovation.
- **Legislators** – Happy constituents (including companies).
- *Made in China 2025* is very different than an American course of action. Innovation and entrepreneurship are areas of focus.

# A new way to make structural parts

Stuff does matter – materials and processing is a big part of our economy and accounts for about 1/3 of the greenhouse gas we produce.

# Metamorphic Manufacturing

- An opportunity to do something establish new processes in the US.
- Treats needs for components (aerospace, heavy industry, medical, etc.) with completely new and simpler production paths.
- Has similar potential to *additive manufacturing*.
- Allows sustainable production of components where they are needed.



German anonymous, circa 1606



# Short Tutorial: How do we make things now...

1. **Take** something from nature (tree, rock, etc.)
2. Cut or **machine** something to size
3. Solidify or cure a liquid in a **mold**
4. Build something from small parts (**add**)
5. **Form** to shape with dies (sheet, forge, etc.)



Example cold-forged parts

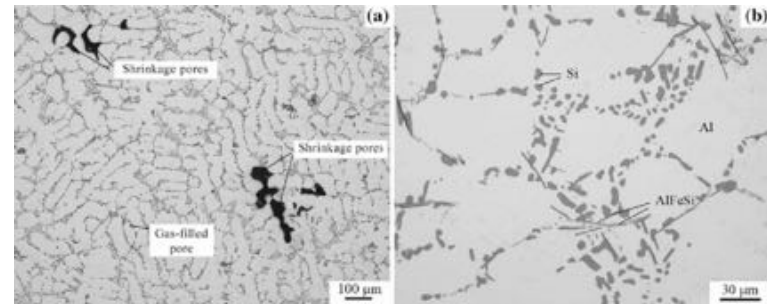
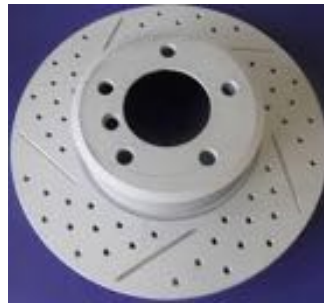


Open and closed die hot forgings

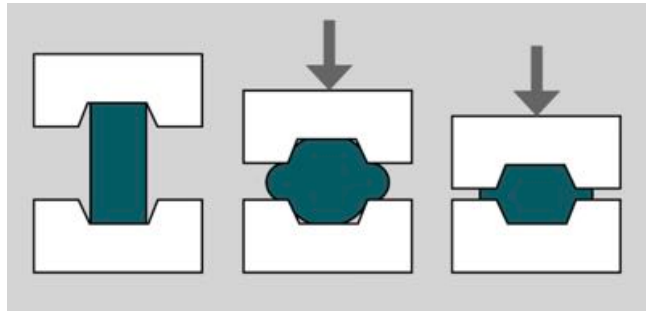


# Cast metal products

- Easy way to complex shape
- Very little waste
- Surprising levels of innovation
- Often poor properties vs. wrought



# Closed Die Forging



Awesome properties

Can be expensive

Long time and big \$ to first part

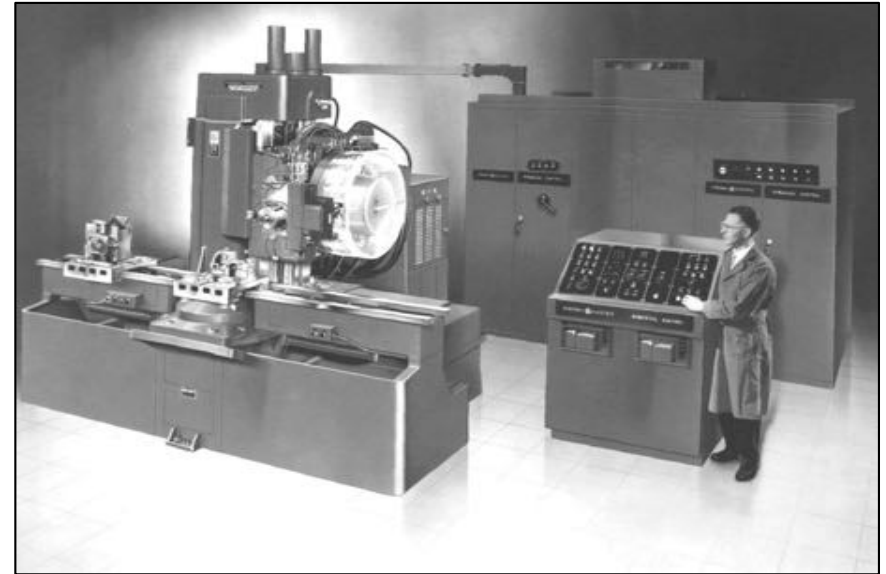
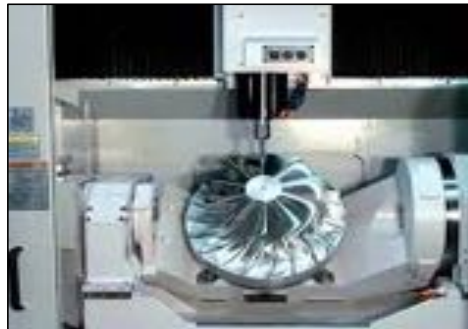


# Digital Manufacturing

- Part description is stored on a computer
- Equipment makes the part without dies or molds
- Flexible, rapid product changes, short lots.
- Potentially sustainable
- Manufacturing can be at point of need.

# CNC Machining

## 1<sup>st</sup> Wave Digital Manufacturing

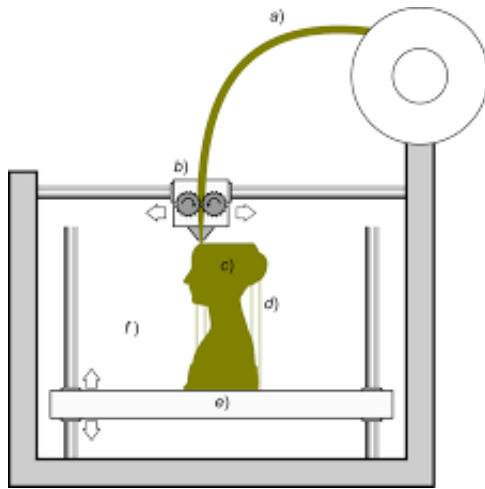


### Subtractive/Removal

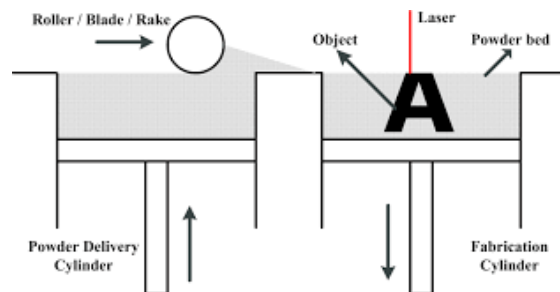
MIT - starting in ~1949

# Additive Manufacturing (a.k.a. 3-D printing)

## 2<sup>nd</sup> Wave of Digital Manufacturing



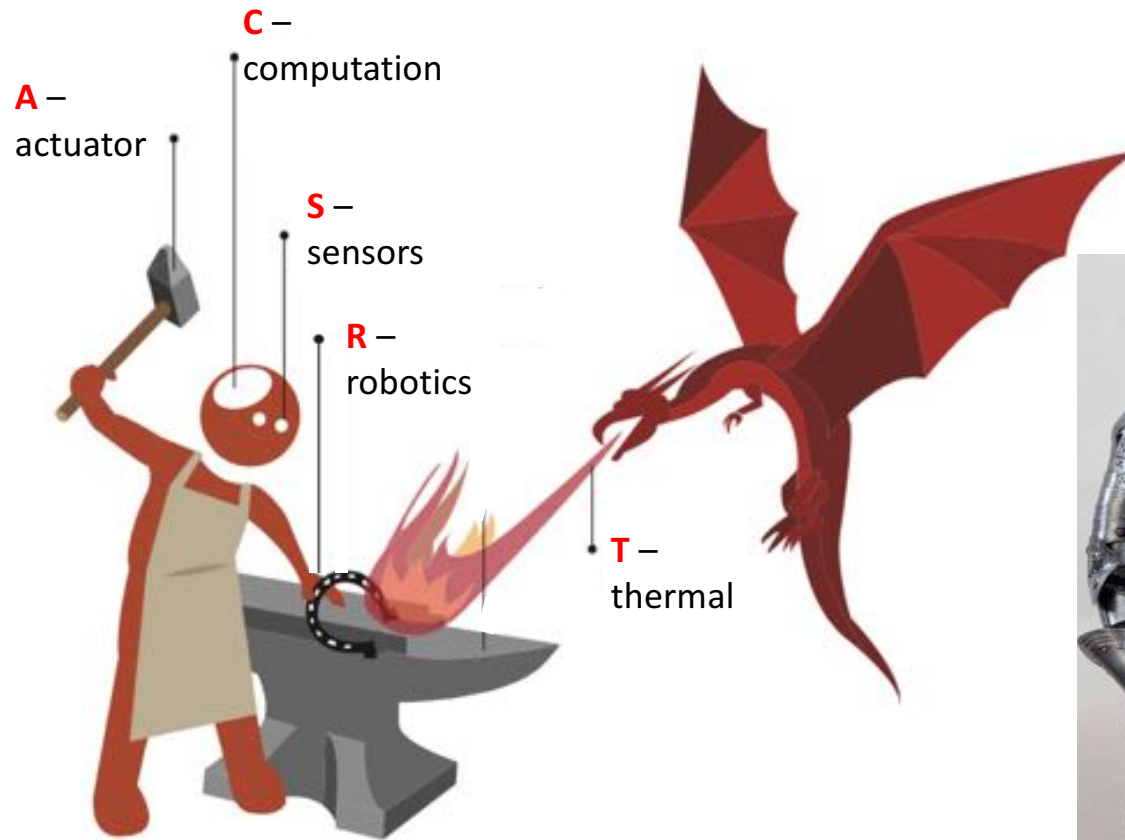
NSF, etc., start early 1980's



Federal spending of hundreds of \$M spent on Additive since the 1990's

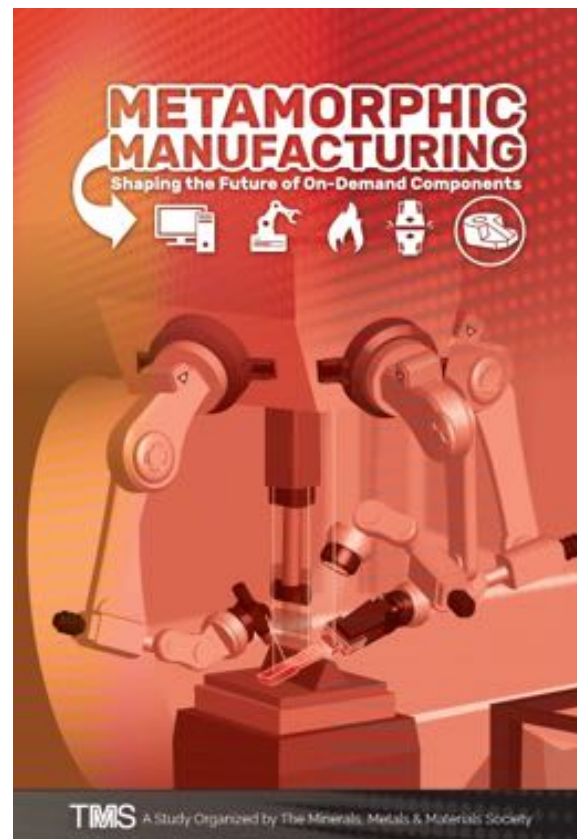
# 3<sup>rd</sup> Wave -- Metamorphic Manufacturing (Manual)

- Change shape
- Change Properties



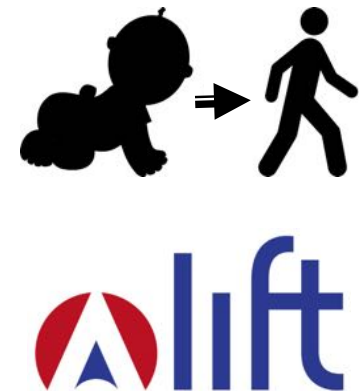
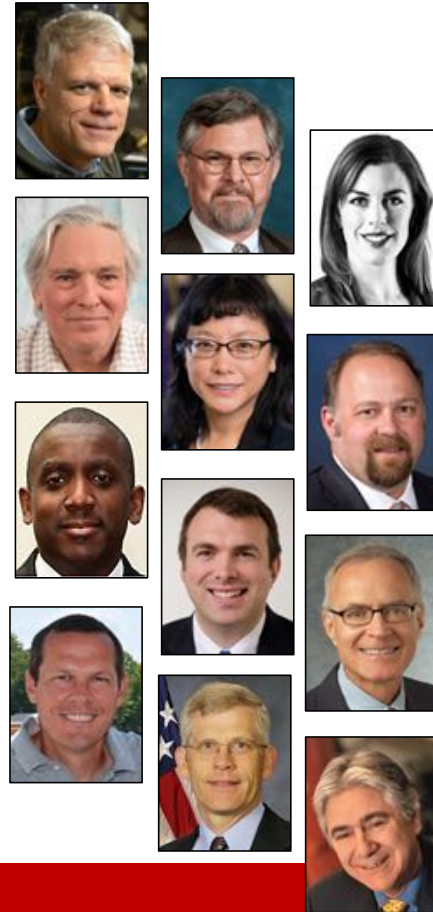
# Metamorphic Manufacturing Study

- Overarching Goal of Study: ***jump start the development, emergence, and growth of this potentially disruptive technology***
- Identifies MM value proposition, foundational underlying technologies, fundamental science and engineering challenges/needs
- Develops recommendations and detailed action plans
- All intended to help community achieve above goal, and ***make quantifiable progress within next 3 years***



# The Study Team

- **Glenn Daehn (Team Chair)** – Ohio State University
- **John Allison** – University of Michigan
- **Elizabeth Bilitz** - Finkl Steel
- **David Bourne** - Carnegie Mellon University
- **Jian Cao** - Northwestern University
- **Kester Clarke** - Colorado School of Mines
- **Johnnie J. DeLoach Jr.** – Office of Naval Research
- **Ed Herderick** – OSU Center for Design & Man. Excellence
- **John Lewandowski** - Case Western Reserve University
- **Tony Schmitz** – University of North Carolina
- **Howard Sizek** – Air Force Research Laboratory
- **A. Erman Tekkaya** –Tech. Univ. of Dortmund



❖ Expertise in varied areas: metals, forging, manufacturing (including additive), welding, deformation, robotics, machines...

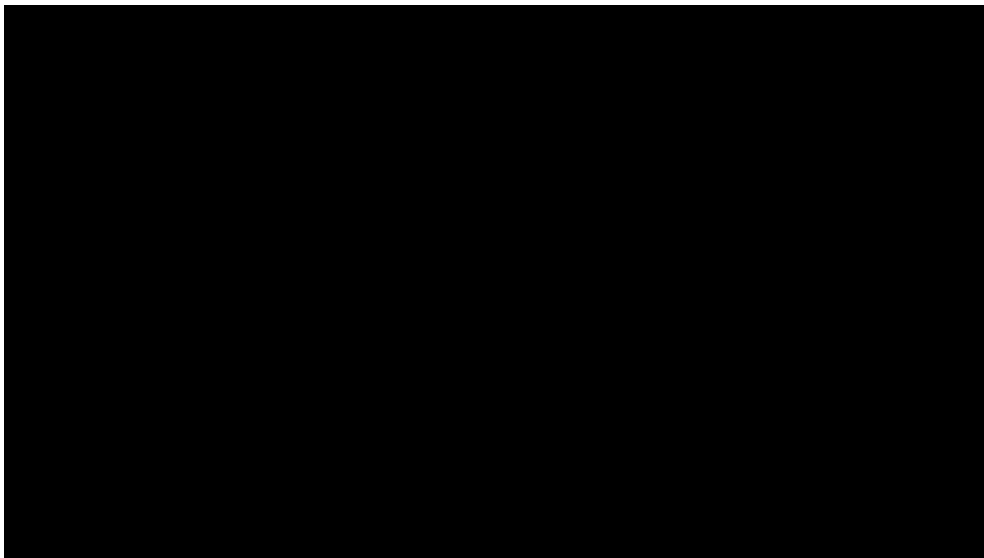
## Key study question:

What would be the benefits and challenges in developing a robust and general capability for the digital reshaping of metal?

What steps are needed to actualize such a vision?

# Foundational ideas

Open die forging



Robotic metal forming



## ***Proof of Concept; The LIFT Prize–***

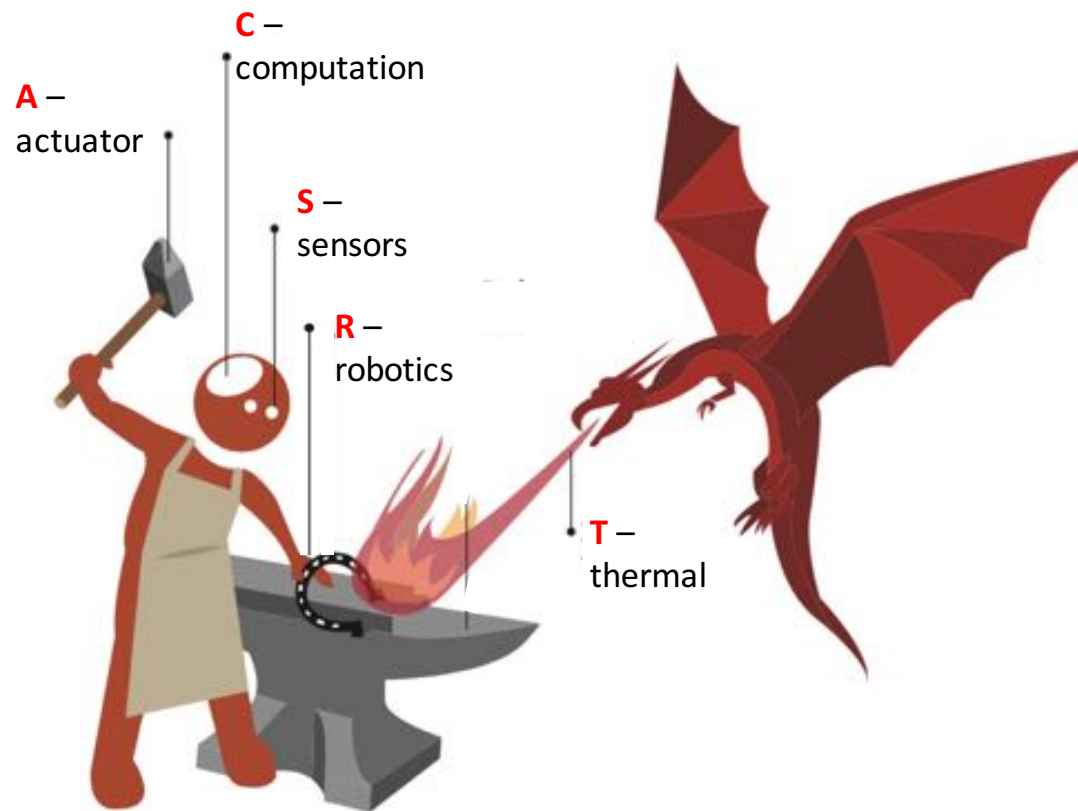


**LIFT Prize** – \$25k offered for a single programmable system that can shape 2 of 3 target parts.

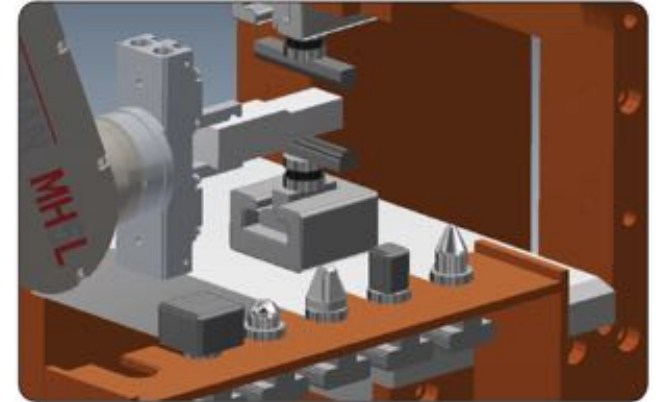
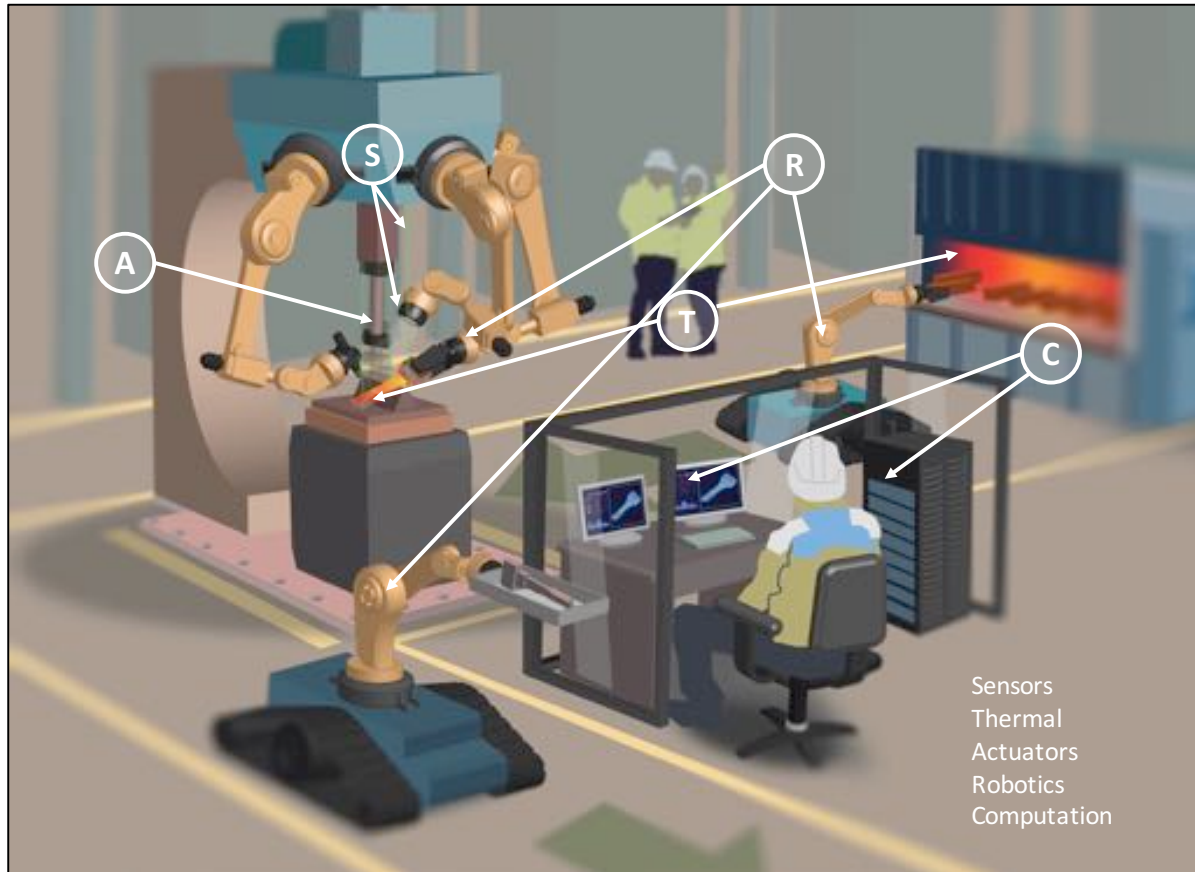
Team Honey Badger, of Ohio State University. Alex Koenig, Bhuvir Nirudhoddi and Brian Thurston

See: [RoboticBlacksmithing.com](http://RoboticBlacksmithing.com) for details.

# Fundamental Elements



# Robotic Blacksmith



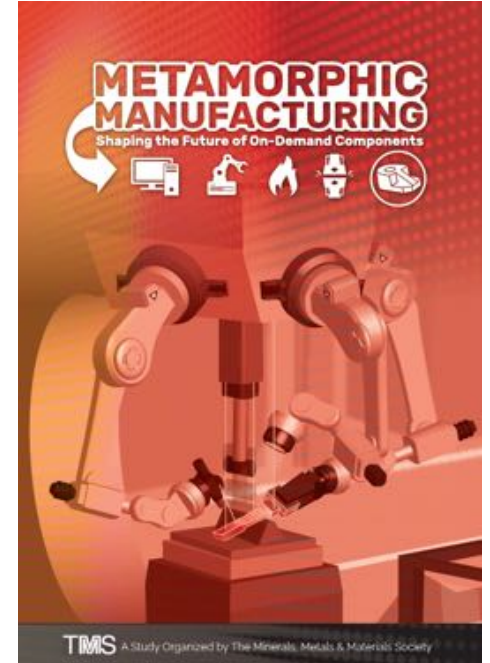
# Report outcome: Value Proposition

3 value  
categories

Table 1. MM Value Proposition and Key Benefits	
Value Proposition Categories	Key Benefits
Economical and Environmentally Friendly	Lower material waste
	Little (or no) need for die fabrication and storage
	Reduced energy consumption and carbon footprint
Shape and Property Control	Superior local property control
	Unique, highly complex shapes/geometries
	Larger build envelope
	Optimization of process routes and properties via iteration (possibly aided by machine learning)
Superior Manufacturing Flexibility and Accessibility	Expanded suite of materials options
	Attractive product lines for many small and medium sized businesses
	Small batch production and part design variability capabilities
	Short lead time from concept to production

## Actions recommended

1. Launch Computational-MM benchmarking & modeling efforts
2. Build prototype MM process suites & exemplar parts
3. Characterize critical-to-quality property drivers for MM materials.
4. Develop MM internship program
5. Foster small organization-led industry-based MM projects
6. Formulate & address some grand challenge problems
7. Create desktop prototype machine



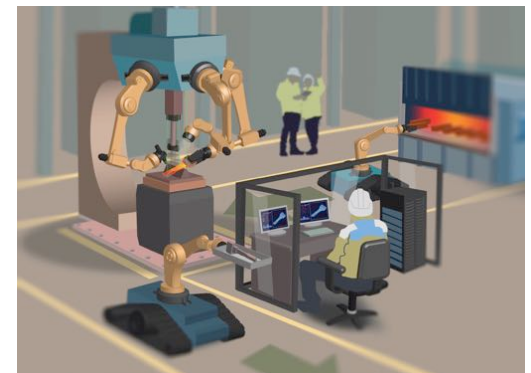
## Example closed-die forged parts



Example forging images from Consolidated Industries: <http://www.consolindustries.com/products-military-forgings.php>

# The 3 waves of digital manufacturing

Technology	1-Subtractive	2 - Additive	3 - Metamorphic
Machine	•	•	•
Tool Path	•	•	•
Material State Control		•	•
Forming Strategy			•
Sense, Compute, Control			•



# Comparing Additive and Metamorphic Manufacturing

## Additive



## Metamorphic

- Wider range of materials
- Less energy consumed
- Scales to larger sizes
- Better materials properties
- Integrates with other processes
- Challenges: awareness, training, tools, algorithms.



# Practical Problem

Bigger problem than usually handled in University environment.

Pre commercial.

Needs many disciplines: Materials, Robotics, Computation, Metrology, Artificial Intelligence, Equipment hosting, etc., etc.

Needs an unusual structure and support.

Useful to find a way to do it here.

# Technical case

Subtract → Add → Morph. (shape and properties)

Based on fast advancing disciplines

- Robotics
- Integrated Computational Materials Engineering
- Artificial Intelligence
- Sensors
- Control

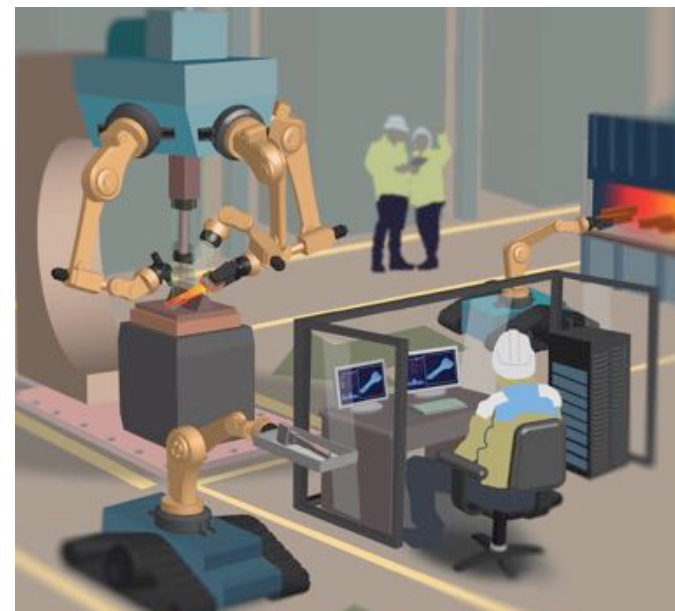
Can scale naturally to large sizes

Provides exceptional materials properties; extendable to graded chemistry

Naturally provides a path for qualification and certification

Is an opportunity for the USA. Helps balance of trade. Cement this here by:

- Fast innovation
- Skilled workforce (motivated by creative opportunity)
- Unique and accessible equipment



## Concluding Remarks...

- D-Day reminds to be self reliant to make what we need in a crisis...
- This process innovation provides infrastructure and skills; hard to move.
- Metamorphic Manufacturing (robotic blacksmithing) offers an opportunity to invest on the ground floor for a new technology. This can provide:
  - Skills
  - Capabilities
  - Jobs
  - Competitive advantages
- Do support manufacturing technology. We need to keep parity with rival countries.